U.S. Department of Transportation
Office of the Secretary of Transportation

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GENERAL COUNSEL
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September 14, 1998

Ms Magalie Roman Salas
Office of the Secretary
Federal Communications Commission
1919 M Street, N.W.
Washington, D.C. 20554

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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

Re: RM 9096
ET Docket No. 98-95

Dear Madame Secretary:

Enclosed please find an original and nine copies of the Comments of the United States Department of Transportation in the above-referenced proceeding.

Respectfully submitted,

Paul Samuel Smith

Paul Samuel Smith
Senior Trial Attorney

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Enclosures

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SEP 14 1998

FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of:	)	
	)	
Amendment of Parts 2 and 90 of the	)	
Commission's Rules to Allocate the	)	RM-9096
5.850-5.925 GHz Band to the	)	ET Docket No. 98-95
Mobile Service for Dedicated Short	)	
Range Communications of Intelligent	)	
Transportation Services	)	
	)	

COMMENTS OF THE
UNITED STATES DEPARTMENT OF TRANSPORTATION

INTRODUCTION

The Federal Communications Commission ("FCC" or "Commission") in this proceeding has proposed to allocate 75 MHz of spectrum for wireless communications between motor vehicles and roadside systems via Dedicated Short Range Communications ("DSRC") services. Notice of Proposed Rulemaking, released June 11, 1998 ("NPRM").[1] These services are an important component of the National Intelligent Transportation Systems ("ITS") program, which Congress has repeatedly identified as a primary means of improving the nation's transportation infrastructure and enhancing safety, efficiency, and the environment. *See* NPRM at 1-3. Indeed, as the Commission notes, this very proceeding responds to recently passed legislation specifically directing it to consider allocating spectrum for DSRC purposes. Section 5206(f), Transportation Equity Act for the 21st Century, P.L. No. 105-178; NPRM at 3-4.

The United States Department of Transportation ("DOT" or "Department") has as one of its fundamental missions the identification, promotion, and development of technologies appropriate to the ITS program effort. Id. This responsibility was

[1]/ References herein to the NPRM, and to its page numbers in particular, conform to the electronic version that the FCC posted on its web site.

evidenced by DOT's support for the rulemaking petition filed last year by the Intelligent Transportation Society of America ("ITS America") that sought the allocation of spectrum for DSRC purposes. Docket RM-9096. [2] The Department at that time concluded that "a permanent allocation is necessary to ensure national compatibility and reliability, which are in turn critical to the widespread deployment of DSRC services that will transform transportation." DOT Comments, filed July 28, 1997, at 3. That remains the case. We continue strongly to support the allocation of spectrum for DSRC services, and we urge the Commission to finalize the instant proposal.

BACKGROUND

Before turning to the issues on which the FCC requested comment, a brief summary of the underpinnings of the ITS program may assist the Commission in placing these issues in context. The FCC correctly notes that Congress first established the National ITS program and charged the Department with responsibility therefor in 1991. NPRM at 3. Working in close cooperation and consultation, many public and private partners throughout the U.S. defined the needs of the National ITS program in a National Program Plan. *See* ITS America Petition ("Petition") at Attachment C. The National ITS Architecture, also the joint product of many parties and involving a significant federal investment, describes the technical and policy principles that inform the development and implementation of ITS technologies, including DSRC. *See* Petition at Attachment F. Together they identify the thirty "user services" that comprise the collective vision for ITS over the next two decades, as well as the technological framework for implementing them. NPRM at 3.

The National ITS Architecture identifies DSRC as the most appropriate medium, in whole or in part, for eleven of the thirty ITS user services. [3] It is therefore a critical

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[2]/ The ITS America petition included many attachments and contained much background information on the ITS program. To avoid repetition, DOT herein will simply summarize pertinent points and reference appropriate parts of that pleading.

[3]/ DSRC systems consist of vehicle-mounted transponders that communicate in the microwave band with roadside "readers."

enabling technology for the realization of current, emerging, and future ITS applications. Adoption of the Commission's proposal will fully meet the needs of the ITS program with respect to DSRC by ensuring that key ITS services will be able to expand to meet anticipated growth, and will remain free of interference in circumstances involving public safety.

We now turn to the issues posed in the order presented in the NPRM.

Need for DSRC-based Services and Spectrum Allocation

The Commission has responded favorably to ITS America's request for 75 MHz of spectrum. NPRM at 9. Noting that other parties have questioned the need for this amount of spectrum and its own interest in spectral efficiency, however, the FCC seeks comment on the proper size of the allocation. Id. at 8-9. The Department supports the Commission's proposal to allocate 75 MHz. The proposal will support current and future use of DSRC services and allow the flexibility necessary to operate with the users currently in the band. Additionally, only an allocation that is large enough to encompass the planned and envisioned range of services will ensure the interest and investment necessary to bring about the enormous potential benefits. NPRM at 9.

The Commission correctly raises the issue of spectrum efficiency. Id. However, prudence dictates reliance upon existing spectrum efficiency levels and technology in considering the amount to allocate. The Department recognizes that technology is not static and that future DSRC devices may well require less bandwidth that the current generation of equipment, but to allocate spectrum on the basis of projections, however desirable or hoped-for, is to risk limiting the implementation of DSRC services and thus the public benefits noted by the FCC. [4] Moreover, critical analysis supports the

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4/ Manufacturers of DSRC are better qualified to comment on the cost, complexity, and technology issues associated with efficiency levels that are mandated by regulation.

allocation of 75 MHz. [5]

It is quite true that the number of bits per hertz of spectrum used by current technology DSRC beacons is considerably lower than might be achieved by other technologies. However, the extremely short range and hence short "frequency reuse distance" of DSRC services overcomes this factor. DSRC is not expected to be a "wide area" service, providing the ubiquitous coverage that might be expected from personal communications services. By its very nature, DSRC is of use only on surface transportation rights-of-way, and the number of users that each beacon can accommodate is established less by the amount of spectrum available than by the sheer number of vehicles that can physically fit within its "footprint." From this perspective, then, it is not clear what benefit would accrue from narrower, more efficient bandwidths. Moreover, the added cost of the more complex equipment required to achieve higher bits per hertz could be a disincentive to implementation, reducing the overall market (and hence the public benefits).

It is also important to consider that bits per hertz is only one measure of efficiency. Throughput is a function of transmission power, data rate, and cost of a given device, as well as bandwidth. DOT encourages the use of more efficient technology and expects improvements over existing efficiencies in the existing DSRC band (902-928 MHz) as well as in the Japanese and European devices that have been tested.

The proposed allocation of 75 MHz also encourages widespread implementation of DSRC technologies by offering the maximum flexibility of operation, which allows installations to avoid interference to and from other incumbents in the band. NPRM at 8-9. Given the existence of other users in this band of both equal and (potentially) lower priority, the frequency "agility" afforded by the 75 MHz allocation minimizes the likelihood of conflicts between users, and hence maximizes the overall use of the band.

[5]/ ARINC, under contract with DOT's Federal Highway Administration, has studied DSRC spectrum requirements in this manner and has concluded that a minimum of 48 MHz is required. Petition at Attachment L. As noted in the text, the frequency agility necessary to ensure interference-free operations with the incumbent users in this band supports the additional 27 MHz allocation.

The Commission has also preliminarily determined that the 5.850-5.925 GHz band is appropriate for the DSRC allocation. NPRM at 8. Again, we agree. The factors considered in arriving at this recommendation include equipment cost, available spectrum, and international acceptability, among others. Spectrum of a higher frequency increases materials costs, spectrum of a lower frequency is more heavily used, and international standards for DSRC equipment are increasingly established in this frequency range.

Spectrum Sharing

The Commission has tentatively concluded that DSRC-based services can share the 5.850 – 5.925 GHz band with existing users, and has requested comment on this subject. NPRM at 11-13. The Department believes that sharing of this band with incumbent users is feasible.

The existence of incumbent users naturally raises the question of interference. DOT has been working with the incumbents and their representatives – particularly the U.S. Department of Defense ("DOD") and INTELSAT -- to ensure that appropriate spectrum sharing is technically feasible. Substantive analysis demonstrates that it is; but reducing the results to a specific regulatory provision has been more difficult. [6] Based on technical analysis, however, the Department submits that DSRC applications and incumbent users can share the relevant band without interfering with each other.

Attachments 1 and 2 hereto are analyses performed by the Institute for Telecommunication Sciences, of Boulder, Colorado. They conclude that DOD's high-powered radars present manageable interference problems for DSRC installations. The analyses, using equipment manufactured to the European and Japanese DSRC standards and modified to operate in the 5.850-5.925 band, demonstrate that the interference ranges

[6]/ We nonetheless concur with DOD that there is a possibility that radars developed in the future could have a different impact on DSRC systems. DOT has accordingly agreed to a footnote in the U.S. Table of Frequency Allocations that would address a coordination zone. Specific wording of this footnote has been forwarded to the Interdepartmental Radio Advisory Committee for final coordination, and will be transmitted to the Commission by the National Telecommunications and Information Administration shortly.

of DSRC devices are very short. In the case of the European standard equipment, a typical worst-case interference range is less than 20 kilometers; in the case of the Japanese standard equipment, it is less than 1 kilometer. [7] It should be borne in mind, of course, that such worst-case scenarios do not take into account various potential mitigation techniques that may eliminate interference even within such limited areas. For example, DSRC operators can employ terrain shielding, directional antennas, RF fencing, and other measures to avoid receiving or causing interference. DOT will also pursue additional analysis to determine more precisely the effectiveness of these techniques, and we expect that appropriate guidelines will be developed in coordination with industry to ensure adequate protection for all users of the band.

The Commission has also proposed that DSRC services be accorded a lower allocation status than industrial, scientific, and medical ("ISM") applications in the pertinent band. NPRM at 14. The nature and uses of ISM equipment are such that DSRC devices should have no difficulty avoiding interference with ISM emitters, assuming sufficient spectrum is available to allow frequency "agility." Again, a 75 MHz allocation would allow users to move about the band and away from sources of interference.

DOT also concurs with the Commission's proposal that coordination responsibility rest with the Interdepartment Radio Advisory Committee. NPRM at 14. We agree as well with the Commission's proposal on Part 15 (*i.e.*, unlicensed) DSRC devices. Id. It is our belief that Part 15 DSRC devices would provide no safety-related services, and thus the lack of protection afforded them would not compromise public safety. Part 15 DSRC devices may, however, find application in various commercial endeavors, in which case the responsibility for proper operation rests with the commercial provider.

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[7]/ The potential for interference is a function of each radar's pulse repetition rate and DSRC communication times. If a DSRC communication takes place between radar pulses, there will be no interference. To reduce any potential for interference, the Department is examining options to reduce DSRC communication times so that they are more likely to fall between radar pulses.

Finally, the Commission would place responsibility for coordination on each of the affected institutions (DOD and Fixed Satellite Service operations) through the Frequency Assignment Subcommittee of the Interdepartmental Radio Advisory Committee). NPRM at 14. This approach should address all significant concerns. The Department also suggests that developing coordination zones around existing high power emitters in the band would ensure that individual DSRC installations select frequencies that are clear of interference whenever possible.

Technical Standards

The Commission has proposed a variety of technical standards. NPRM at 14-24. DOT offers its comments thereon in Attachment 3.

Other Issues

The Commission has proposed to adopt the definition for DSRC services contained in the ITS America Petition. NPRM at 23-24. The Department supports this proposal. This definition is substantially broader than the definition now used for a single DSRC service (Location and Monitoring Services or "LMS") under Part 90 of the FCC's rules, and properly so. DSRC technologies at 5.9 GHz will embrace a much broader range of services and thus prove to be of far greater value if this more encompassing definition is used to guide the development of DSRC equipment.

There is one limitation in the proposed definition that DOT wishes to underscore -- the exclusion of voice transmissions. The ITS America definition specifically stipulates that DSRC is a data service. We believe that permitting voice services would have the potential eventually to overwhelm data services, which would have severe effects on the safety-related services provided by DSRC. [8] Voice communications between roadside and vehicles is not required under the ITS National Architecture to provide any of the user services identified as appropriate DSRC applications, and hence should not be

[8]/ DOT does not intend hereby to preclude the use of a synthesized voice generated within vehicles to announce messages. Such a system might be used for in-vehicle signing, in which a synthesized voice relaying text messages might be the most appropriate interface with the driver.

permitted. Numerous other technologies, operating at other parts of the electromagnetic spectrum, offer voice services; and no such additional services should be provided in this band.

Conclusion

The Commission has responded favorably and properly to the ITS America petition. Allocation of 75 MHz of spectrum in the 5.850-5.925 GHz band will encourage and accommodate both existing and future DSRC services, to the substantial benefit of the traveling public. The proposal will also allow interference-free operations with incumbent users in this band. Finally, the proposed allocation will strongly advance national and international interoperability of DSRC devices, and thereby further their implementation. The Department accordingly urges the FCC to finalize its proposed allocation.

Respectfully submitted,

Nancy E. McFadden

NANCY E. MCFADDEN
General Counsel

September 14, 1998

Attachment 1

ELECTROMAGNETIC COMPATIBILITY TESTING OF A DEDICATED SHORT-RANGE COMMUNICATION (DSRC) SYSTEM

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U.S. Department of Commerce

for

Federal Highway Administration
U.S. Department of Transportation

August 26, 1998

EXECUTIVE SUMMARY

The Department of Transportation is investigating the feasibility of deploying dedicated short-range communication (DSRC) systems at locations across the United States in the 5850 to 5925 MHz band. This is part of a larger band, 5250-5925 MHz, which is currently allocated to radar services. Deployment of DSRC systems depends upon the electromagnetic compatibility of their operations with radar systems operating in the 5-GHz portion of the spectrum.

Electromagnetic compatibility tests of a DSRC system that conforms to Japanese standards were performed by the Institute for Telecommunication Sciences. The purpose of the tests was to determine to what extent the DSRC system may experience electromagnetic compatibility problems when in close proximity to high-power radars in the 5-GHz spectrum. The tests were performed by injecting simulated radar signals into a DSRC receiver. The radar signals are representative of the range of parameters used by existing and possible future radars.

Thresholds at which the radar signals caused degradations of DSRC system performance were measured for each set of radar signal parameters. These measured interference thresholds were then used to determine the received signal levels at which existing 5-GHz radars would be expected to interfere with DSRC systems deployed in the United States. For each type of radar, the distance at which the radar system would be expected to cause interference to the DSRC system was computed for various conditions of electromagnetic isolation between the two systems. This analysis indicates that for typical conditions of isolation and nominal operating conditions of the DSRC system that was tested, 5-GHz radars are not expected to interfere with DSRC operations for any realistic separations between the systems (greater than several meters).

ELECTROMAGNETIC COMPATIBILITY TESTING OF A DEDICATED SHORT-RANGE COMMUNICATION (DSRC) SYSTEM

John J. Lemmon
Frank H. Sanders
Brent L. Bedford

1.0 INTRODUCTION

1.1 Background

As part of the planning of an intelligent transportation system, the Department of Transportation is evaluating the performance of dedicated short-range communication (DSRC) systems. DSRC systems are wireless communication systems designed for operation in highway environments. Their purpose is to enhance the efficiency of highway travel by providing various vehicle-to-roadside services such as wireless interrogation stations that would collect tolls electronically as vehicles pass through the stations without stopping.

The portion of the spectrum between 5850 MHz and 5925 MHz has been identified as a likely band for deployment of DSRC systems in the United States. This band is part of a larger band (5250-5925 MHz) that is allocated on a primary basis for radiolocation (radar) systems. The band is occupied in the United States by high-power radar systems that could potentially interfere with DSRC systems in highway environments.

The Institute for Telecommunication Sciences (the Institute) recently tested a DSRC system for its response to high incident field strengths in the 5250-5925 MHz band. Tests were performed to determine the interference thresholds at which DSRC performance was degraded. The methodology and results of these tests have been discussed in a report by Dalke, Sanders, and Bedford [1].

The DSRC system described in [1] is based on European standards, and will hereafter be referred to as the European DSRC. More recently the Institute performed analogous tests on a DSRC system that conforms to Japanese standards. The purpose of this Sponsor Letter Report is to describe the methodology and results of these latter tests.

1.2 Approach

The tests were performed in a laboratory at the Institute for Telecommunication Sciences in Boulder, CO. Unlike the tests of the European DSRC, no tests of the Japanese system were performed in an outdoor environment because the manufacturer advised Institute engineers that the prototype DSRC under test was not resistant to rainy weather conditions. The basic approach to the tests was to inject simulated radar signals into the DSRC and to determine the interference levels, for various radar signal modulations, at which performance degradations of the DSRC would occur for both co-channel interference and off-frequency interference.

As discussed in [1], radar beams typically scan across any given point in space repetitively, approximately every 3-10 seconds, and illuminate any given point (such as a DSRC station) for about 20 ms during a given beam-scan period. The signals consist of a repetitive series of pulses that are characterized by the pulse width and pulse repetition interval. Two related parameters are the duty cycle (pulse width divided by pulse repetition interval) and the pulse repetition frequency (reciprocal of the pulse repetition interval). The pulse parameter combinations that were selected for the interference testing are representative of the parameters for 5-GHz radars in the United States and are shown in Table 1-1. For each combination of duty cycle and pulse repetition frequency (or pulse repetition interval), the corresponding pulse width is shown in the table.

Table 1-1. Radar parameters used for DSRC interference signal testing.

	prf = 300 Hz pri = 3.3 ms	prf = 1000 Hz pri = 1 ms	prf = 3000 Hz pri = 330 μs
Duty cycle = -20 dB (1%)	33.3 μs	10 μs	3.3 μs
Duty cycle = -30 dB (0.1%)	3.3 μs	1 μs	0.33 μs
Duty cycle = -40 dB (0.01%)	0.33 μs	0.1 μs	0.03 μs

For each interference signal modulation that was tested, the interference level was initially adjusted to a very low amplitude, well below the level that adversely affects DSRC performance. The amplitude was then gradually increased until an adverse effect on DSRC performance was noted.

1.3 Experimental Configuration

The hardware configuration used for the testing is shown schematically in Figure 1-1. The units under test, a DSRC roadside unit (RSU) and a DSRC on-board unit (OBU), were mounted on separate tripods in an Institute laboratory and were separated by approximately 2.8 m. The RSU was operated from a laptop PC via an RS-232 connection. The RSU transmitted to the OBU at a frequency of 5860 MHz. The OBU responded to the RSU at 5900 MHz. The OBU operated autonomously, its only external connection being for power.

As pointed out in [1], the uplink of the European DSRC is more susceptible than the downlink to interference signals, so that interference signals were coupled into the RSU receiver. Similar considerations apply to the Japanese system. As in the tests of the European DSRC, the signals were coupled via hardline, rather than via RF radiation, to better control the amplitudes at which the interfering signals were injected into the receiver. A broadband RF combiner was utilized between the RSU antenna and the RSU receiver, as shown in Figure 1-1.

Interference signals were generated using a pulse-waveform generator. That output was then routed to the input of an HP-8661 signal generator to generate RF energy at the proper amplitudes and frequencies for the tests. The interfering signal was then coupled into the RSU receiver via the broadband combiner, along with the desired signal from the RSU antenna.

As shown in Figure 1-1, a monitoring antenna was also used in the RSU-OBU propagation path to observe time-domain and frequency domain emissions from the RSU and OBU during the tests. The monitor antenna output was connected to a spectrum analyzer, whose detected video output was monitored on an oscilloscope. Data from the spectrum analyzer and the oscilloscope were recorded via a GPIB bus interface.

Calibration of the measurement system and of the DSRC performance parameters was discussed in [1], and will not be repeated here.

2.0 DSRC SOFTWARE DESCRIPTION

The DSRC system could not be operated under manual control. The RSU operations were controlled by the software, and the OBU operated autonomously. Test results were obtained through outputs from the DSRC software.

Communication control of the DSRC system is based on a synchronous adaptive slotted ALOHA system. This is a time-division multiple access system in which the number of slots in a frame can be varied; for the interference tests the DSRC was operated in an automatic toll collection mode with a frame structure consisting of four slots. Each slot comprises 800 bits at bit rate of 1 Mbps. Thus, each frame had a time duration of 3.2 ms. The time between frames is also variable; however, during the tests the frames were transmitted continuously to minimize the possibility of interference pulses being injected into the DSRC receiver during 'dead time'.

As explained in [1], the performance parameter that was measured during the tests of the European DSRC is a quantity called wait time, which is essentially the time required for a transaction to take place. In the case of the Japanese DSRC, the wait time is not an output of the software. Instead, the number of frame errors on the DSRC uplink was measured for a user-specified number of transactions. The maximum number of transactions that the system will automatically conduct is 999, which is the number that was used for the tests.

The software also enables the user to specify a maximum number of frames that may be retransmitted during each transaction when one or more frames are in error. The number chosen for the DSRC tests was ten, which is the system default value. The experimenters discovered that the number of uplink "frame errors" is strongly dependent upon the number of retransmitted frames. For example, it was noted that when the number of retransmitted frames was set to zero, the number of uplink frame errors increased to a large value even when no interference was injected into the RSU receiver. Thus, the interference thresholds at which DSRC system performance is adversely affected depend upon the value selected for the number of retransmitted frames. The system default value of ten was selected, because it was felt that this is representative of actual system deployment.

3.0 MEASUREMENT RESULTS AND DATA ANALYSIS

3.1 System Performance Measurements

Figures 3-1 and 3-2 show RSU and OBU spectra measured with a 10 dBi horn antenna located 1.7 m from the DSRC antennas. Institute engineers also measured the effective isotropic radiated powers of the RSU and OBU transmitters, the gains of the RSU and OBU antennas, and the frequency response of the preselection bandpass filter in the RSU receiver unit. The frequency response of this filter and the RSU antenna gain (determined to be approximately 15 dB) are of particular importance, because they are used in the analysis discussed in Section 3.4 below.

3.2 Statistical Measurements of DSRC System Performance in the Presence of Pulsed Radar Interference

The time and phase of a pulsed radar signal are random with respect to the DSRC transmissions. Thus, the number of frame errors is a random variable. Determination of the interference thresholds at which DSRC system performance is degraded therefore requires a statistical characterization. Using the measurement equipment and methods described above, uplink frame error statistics were measured for each of the nine radar signal modulations in Table 1-1 based on 999 independent transactions.

The interference thresholds at which uplink frame errors were generated are shown in Table 3-1. The maximum interference signal level that was output from the signal generator was 10 dBm. Subtracting 6 dB for combiner loss and an additional 6 dB for cable loss, a maximum signal level of -2 dBm was injected into the RSU receiver. A possible concern is that this is not a sufficiently high value for the maximum interference level since uplink frame errors were not generated for five of the nine radar signal modulations (this is why five of the interference power level are designated as >-2 dBm in Table 3-1). However, as will be seen below, if interference signal levels of -2 dBm do not generate frame errors, the radars in the 5-GHz band and the DSRC system are electromagnetically compatible even at extremely small physical separations (several meters or less). Thus, it was not considered necessary to inject larger interference signal levels for the purposes of these tests.

Table 3-1. Peak pulsed interference power levels resulting in uplink frame errors for various radar parameters (pw = pulse width, dc = duty cycle, and prf = pulse repetition frequency).

Radar Parameters	Interference Power Level (dBm)
prf = 300 Hz pw = 33.3 μs dc = 1%	> -2
prf = 300 Hz pw = 3.3 μs dc = 0.1%	> -2
prf = 300 Hz pw = 0.33 μs dc = 0.01%	> -2
prf = 1 kHz pw = 10 μs dc = 1%	-2
prf = 1 kHz pw = 1 μs dc = 0.1%	-2
prf = 1 kHz pw = 0.1 μs dc = 0.01%	> -2
prf = 3 kHz pw = 3.3 μs dc = 1%	-52
prf = 3 kHz pw = 0.33 μs dc = 0.1%	-12
prf = 3 kHz pw = 0.033 μs dc = 0.01%	>-2

3.3 Frequency Offset Measurements

The measurements described above, in which the interference center frequency is equal to the center frequency of the RSU receiver (co-channel interference) is the worst-case scenario, since the RSU receiver has a preselection bandpass filter. To determine the DSRC performance when the interference signal is offset in frequency, the number of uplink frame errors was measured at various frequency offsets. Allowing up to ten retransmitted frames per transaction (as was done for the co-channel testing) resulted in no uplink frame errors for offsets more than a few MHz. Therefore, the frequency response of the preselection filter in the RSU receiver was measured to ascertain system performance with frequency offsets. The frequency response is shown in Figure 3-3. The attenuation of the filter (as a function of frequency) relative to the center frequency provides additional isolation between the DSRC and an interferer that is offset in frequency.

3.4 Analysis of Results

Using the measurement results described above, the required isolations between the DSRC and an interfering radar have been determined for a variety of cases. High-power radars operating in the 5-GHz band typically have peak effective isotropic radiated power (EIRP) in the range of 113-133 dBm. The worst case interference degrades DSRC system performance at power levels as low as -52 dBm, as indicated in Table 3-1. Assuming an RSU antenna gain of 15 dB, at least 180-200 dB of isolation is required. The best case interference (from Table 3-1) occurs as power levels greater than -2 dBm, requiring 130-150 dB of isolation.

The physical separation between the DSRC system and the interfering radar necessary to achieve the best and worst case isolation is shown in Table 3-3. These separations correspond to those distances at which the basic transmission loss equals the required isolation. The basic transmission loss as a function of distance was calculated using the ITS irregular terrain model for a typical environment with the parameters shown in Table 3-2.

Table 3-2. ITM parameters used to calculate basic transmission loss.

Parameter	Value
Frequency	5850 MHz
Polarization	Vertical
Antenna heights	13 m (radar), 6.1 m (DSRC)
Terrain irregularity	90 m
Surface refractivity	301 N-units (4/3 earth)
Climate	Continental temperate
Electrical ground constants	$\sigma = 0.005$ S/m, $\epsilon_r = 15$
Time reliability, location reliability, and confidence level	90%, 90%, 50%

The above estimates assume co-channel interference and peak directivity for both the radar transmit antenna and the DSRC receive antenna. Additional isolation can be achieved when the DSRC is installed so that the interferer is out of the receiver antenna main beam. As pointed out in [1], it is estimated that an additional 15 dB of isolation can be achieved for such an installation. It is also estimated that when the DSRC system is well out of the main beam of the radar, an additional 25 dB of isolation may be obtained. Thus, an additional 40 dB of isolation may be realized by antenna alignment.

The measurement of the frequency response of the preselection bandpass filter in the RSU receiver, shown in Figure 3-3, indicates that about 70 dB of additional isolation may be achieved for frequency offsets of a few hundred MHz. This attenuation in combination with antenna sidelobe attenuation provides adequate isolation for effective operation of the DSRC system that was tested.

To compare these possibilities, Table 3-3 gives the required best case and worst case isolations and the corresponding physical separations between the radar and the DSRC system for the following cases:

Case 1, isolation is achieved via physical separation only.

Case 2, isolation is achieved via physical separation and antenna alignment, which provides an additional 40 dB of isolation.

Case 3, isolation is achieved via physical separation and frequency offset, which provides an additional 70 dB of isolation.

Case 4, isolation is achieved via physical separation, frequency offset, and antenna alignment, which provides an additional 110 dB of isolation.

Table 3-3. Required separation between an interfering radar and the DSRC system to achieve best and worst case isolation.

Required isolation	Case 1 required separation	Case 2 required separation	Case 3 required separation	Case 4 required separation
< 130 dB	< 7.1 km	< 0.133 km	< 0.004 km	< 0.001 km
< 150 dB	< 24.8 km	< 1.1 km	< 0.040 km	< 0.001 km
180 dB	64.4 km	14.0 km	1.1 km	< 0.013 km
200 dB	203.5 km	39.8 km	7.1 km	0.133 km

These results indicate that when the DSRC and radar antennas are aligned so that the radar is viewed with minimum directive gain for both antennas, and the center RF frequencies are offset by a few hundred MHz, the two systems should be compatible at separation distances of approximately 0.1 km for the worst case required isolation of 200 dB (EIRP = 133 dBm). If 180 dB of isolation is required (EIRP = 113 dBm), the systems should be compatible at distances of approximately 10 m. At these extemely small separation distances, the condition for minimum directive gain should be realized for both antennas.

Table 3-4 shows the results of interference calculations for specific existing radars that could potentially interfere with DSRC systems in the 5-GHz band. The radars and their operating characteristics were taken from the Government Master File.

Table 3-4. Required separation distances between specific interfering radars and the DSRC system for different isolation cases.

Specific radar	Case 1: Isolation by physical separation only	Case 2: Isolation by physical separation and 40 dB from antenna alignment	Case 3: Isolation by physical separation and frequency offset	Case 4: Isolation by physical separation, frequency offset, and 40 dB from antenna alignment	Case 5: Isolation by physical separation, frequency offset, and 15 dB from antenna alignment
RIR-778C/FRS-16 1 μs, 1 kHz MIP*=4 dBm	24.8 km 150 dB	1.1 km 110 dB	0.007 km Δf=50 MHz 65 dB	<0.001 km 25 dB	<0.001 km 50 dB
Test radar 10 μs, 1 kHz MIP=4 dBm	16.8 km 143 dB	0.54 km 103 dB	<0.001 km Δf=180 MHz 33 dB	<0.001 km -7 dB	<0.001 km 18 dB
Test radar 3.3 μs, 303 Hz MIP>4 dBm	<16.8 km <143 dB	<0.54 km <103 dB	<0.001 km Δf=180 MHz <33 dB	<0.001 km <-7 dB	<0.001 km <18 dB
SPS-10 1 μs, 1 kHz MIP=4dBm	7.1 km 130 dB	0.133 km 90 dB	0.009 km Δf=25 MHz 67 dB	<0.001 km 27 dB	<0.002 km 52 dB
SPS-10 3.3 μs, 303 Hz MIP>4dBm	<7.1 km <130 dB	<0.133 km <90 dB	<0.009 km Δf=25 MHz <67 dB	<0.001 km <27 dB	<0.002 km <52 dB
SPS-67 1 μs, 1 kHz MIP=4dBm	8.2 km 132 dB	0.166 km 92 dB	0.011 km Δf=25 MHz 69 dB	<0.001 29 dB	0.002 km 54 dB
SPS-67 0.33 μs, 3.03 kHz MIP=-6 dBm	15.8 km 142 dB	0.485 km 102 dB	0.036 km Δf=25 MHz 79 dB	<0.001 km 39 dB	0.006 km 64 dB
WSR-74C 1 μs, 1 kHz MTP=4dBm	14.9 km 141 dB	0.435 km 101 dB	<0.001 km Δf=200 MHz 29 dB	<0.001 km -11 dB	<0.001 km 14 dB
WSR-74C 3.3 μs, 303 Hz MIP>4dBm	<14.9 km <141 dB	<0.435 km <101 dB	<0.001 km Δf=200 MHz <29 dB	<0.001 km <-11 dB	<0.001 km <14 dB

*Minimum interference power (MIP)

In the first column we give the specific radar identification, the radar pulse parameters (pulse width and pulse repetition frequency), and the measured minimum interference power (MIP) for the pulse parameters. The pulse parameters were matched as closely as possible to the measurement results in Table 3-1 to estimate the MIP for each radar. For most of the radars there is a range of possible pulse widths and repetition frequencies, resulting differences in the required isolation. In these cases we have shown the best and worst cases associated with each radar.

In the following columns of Table 3-4, we give the results for each of the four previously defined cases and for a fifth case, where the DSRC antenna is in the main beam of the radar antenna, and the additional isolation due to antenna alignment is 15 dB. There are two table entries for all cases: the required isolation and the physical separation required to achieve that isolation. For Case 3, there is an additional entry showing the value of the frequency offset (Δf) that was used to estimate the value of isolation due to frequency offset (from Figure 3-3). These frequency offsets are the minimum offsets based on the radar RF frequency range and the proposed DSRC system RF frequency range.

Cases 4 and 5 have extremely small separation distances (several meters or less). As pointed out in [1], Case 4 should be achievable in most cases. Case 5 could occur if, for example, if a non-rotating radar is pointed at the DSRC antenna sidelobe, and requires 25 dB more isolation than Case 4. However, even for this case the required separations are several meters or less.

Cases 1 only occurs when the radar and the DSRC are co-channel and additional isolation due to antenna alignment cannot be achieved. However, even for this worst case scenario, the maximum separation distance is less than 25 km (for the RIR-778C tracking radars).

4.0 SUMMARY

The operation of the DSRC system that was tested was found to be affected by co-channel radars with pulse parameters that are representative of high-power radars operating in the 5-GHz band. To achieve the necessary isolation between the radars and the DSRC system, separation distances of tens of km or less are required. Our results also indicate that significant additional isolation can be achieved when the RF frequencies are offset by more than 25 MHz. When combined with the additional isolation achieved by antenna alignment (estimated to be 40 dB), we found that all of the existing 5-GHz radars should be compatible with the DSRC system that was tested for extremely small separation distances (several meters or less).

One should be cautious in making any quantitative comparison between the results of the tests of the Japanese DSRC system described here and the test results of the European system discussed in [1]. In the tests described here, the performance quantity that was measured was the number of uplink frame errors, whereas wait time was measured in [1]. Without more information than the software of these two systems provided, we were unable to measure the relationship between wait time and uplink frame errors. Thus, a direct comparison of the electromagnetic compatibility of the Japanese and European systems does not appear possible at this time.

It should also be realized that the number of uplink frame errors that was measured is dependent upon the number of retransmitted frames per transaction. For these tests, the system default (maximum of ten retransmitted frames per transaction) was chosen, because it is believed that this is representative of actual deployment of the DSRC that was tested.

5.0 REFERENCE

[1] R. A. Dalke, F. H. Sanders, and B. L. Bedford, "Electromagnetic compatibility testing of a dedicated short-range communication system," NTIA Report 98-352, July 1998.

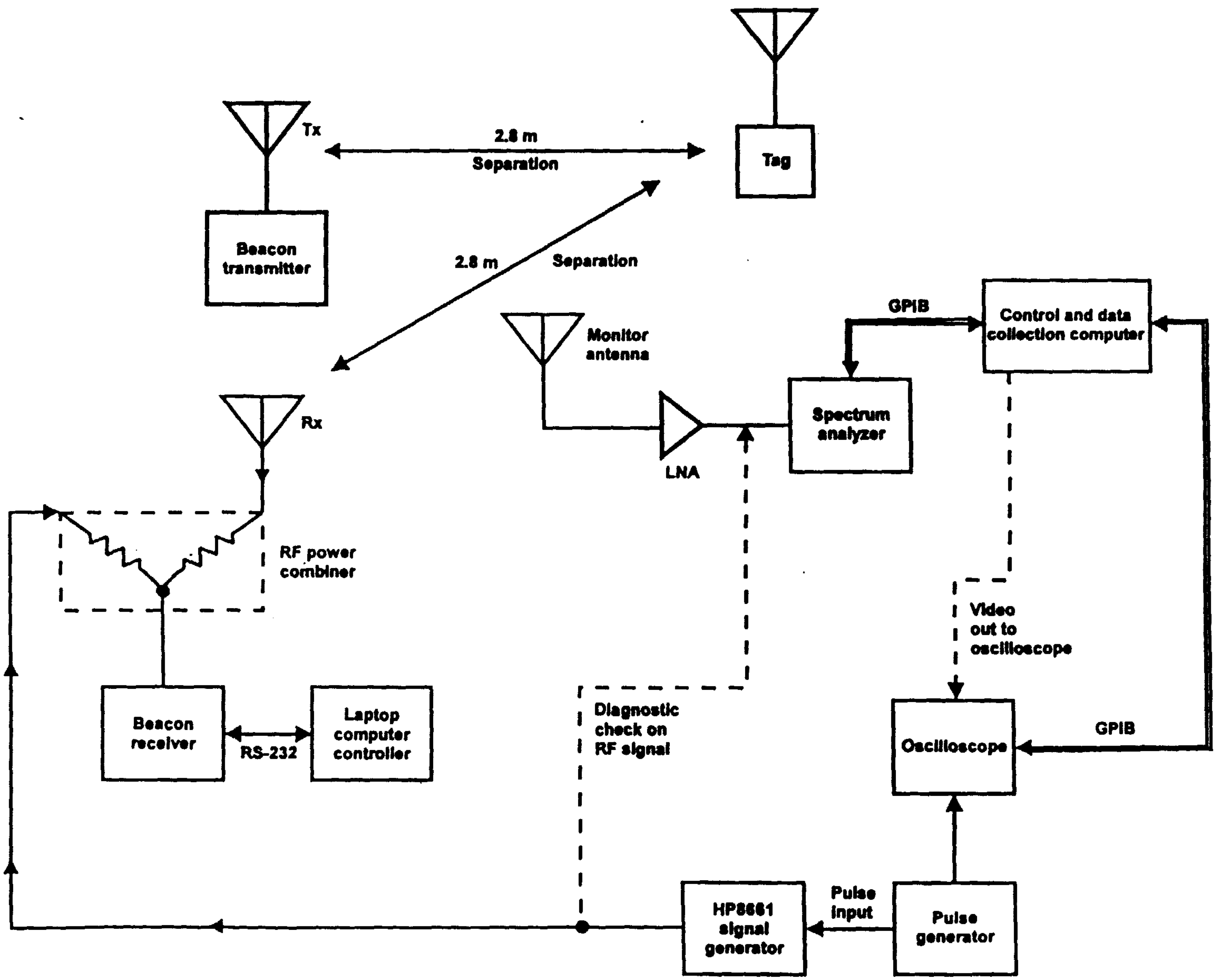

Figure 1-1. Block diagram of interference testing arrangement.

Figure 3-1. Emission spectrum of the RSU.

VFR:001:006:007 D:980520 T:163732 LOCN:ITS Labs,

AG/P:1/1 PREAMP:OFF PRESEL:OFF TEST:

NF:00.0 SN:-148.3 AC:00.0 RBW:00100.000 VBW:00100.000 DW:000.050 DET:2

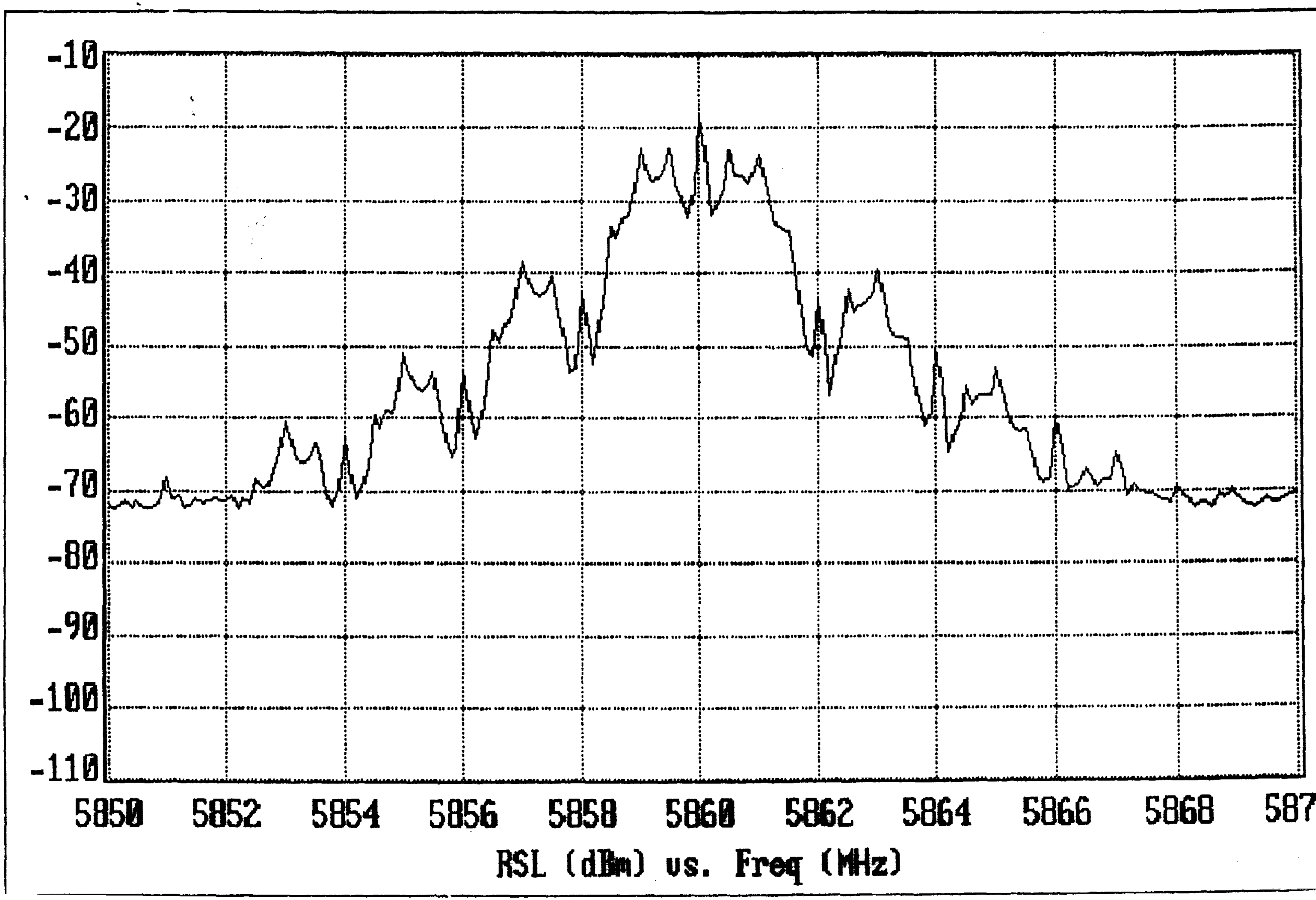

Figure 5-2. Emission spectrum of the OBU.

VFR:001:014:001 D:980620 T:094032 LOCN:ITS Labs,
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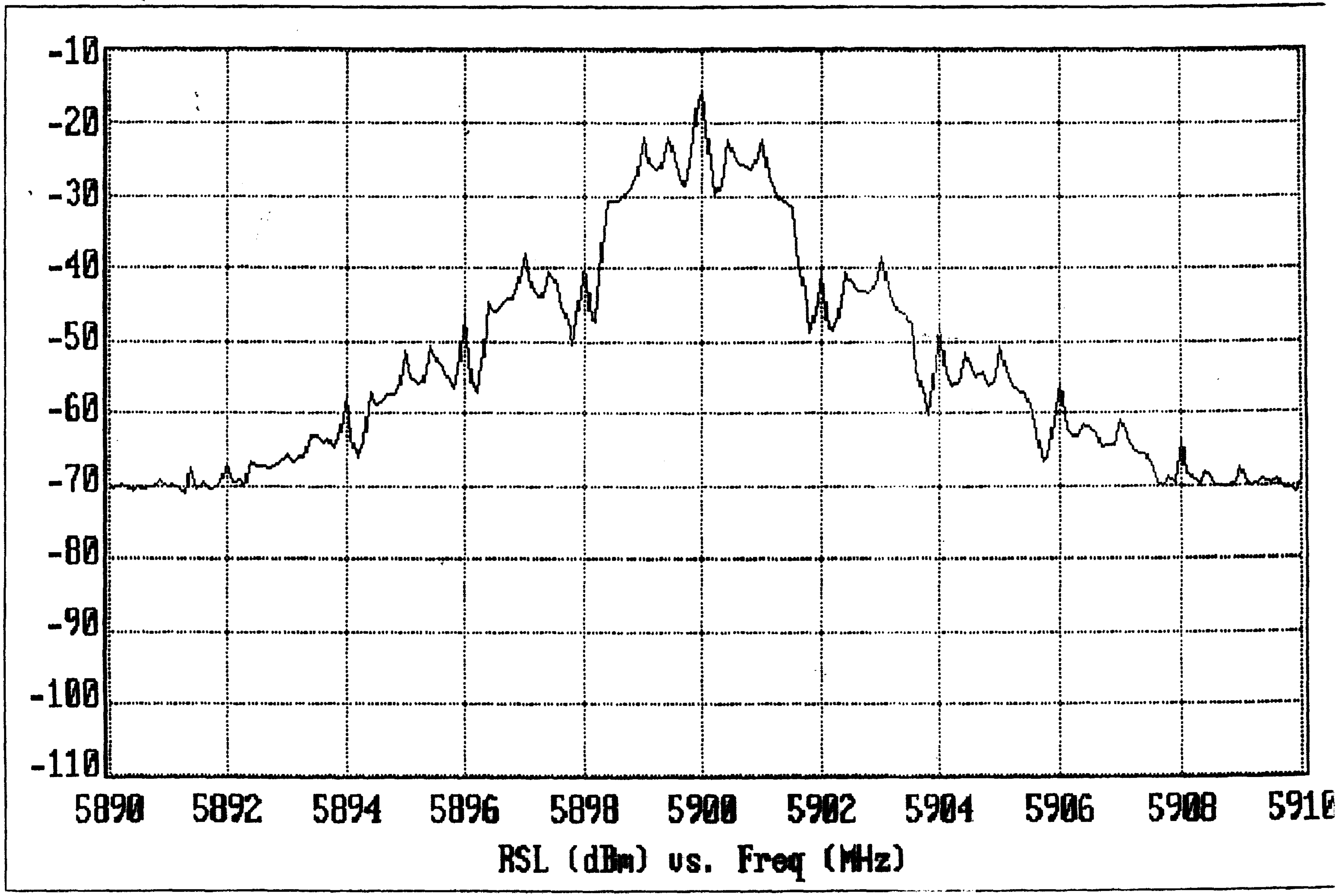

Figure 3-3. RSU receiver preselection bandpass filter frequency response.

VFR:001:013:033 D:980527 T:011342 LOCN:ITS Labs,
AG/P:1/0 PREAMP:OFF PRESEL:OFF TEST:bandpass filter frequency response
NF:00.0 SN:-148.3 AC:00.0 RBW:03000.000 VBW:03000.000 DW:001.000 DET:2